Design and optimization of on-grid hybrid renewable energy system for both irrigation and electrification of village in Khyber Pakhtunkhwa

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Supervisor: Dr. Hassan Abdullah Khalid

Co-Supervised by: Dr Syed Ali Abbas Kazmi

US-Pakistan Center for Advanced Studies in Energy (USPCAS-E)

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Signature (Dean/ Principal) ____________________

Date: 13/05/2024

National University of Sciences & Technology

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No part of this thesis has been submitted anywhere else for any other degree. This thesis is submitted to the US-Pakistan Center for Advanced Studies in Energy (USPCAS-E) in partial fulfillment of the requirements for the degree of Master of Science in Field of Electrical Engineering Department of USPCAS-E National University of Sciences and Technology, Islamabad.

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DEDICATION

With deepest reverence to the Most Gracious and Merciful, I humbly dedicate this thesis to my beloved parents. Your unwavering devotion, boundless support, and endless encouragement have been the cornerstone of my journey. This thesis serves as a tribute to your sacrifices, steadfast belief in my potential, and unwavering commitment to my aspirations. Your invaluable guidance has sculpted my character and fueled my ambitions. I am profoundly grateful for your unwavering faith in me and for being the guiding light in my life.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

HEEs	Hybrid Energy System
HOMER	Hybrid Optimization Model for Electric Renewables
COE	Cost of Energy
WEO	World Energy Outlook
WT	Wind turbines
WAPDA	Water and Power Development authority
NASA	National Aeronautics and Space Administration
GHG	Green House Gases

ABSTRACT

Integration of remote areas with a national grid system is an unresolved dilemma for developing economies. Additionally, a significant portion of electrical energy produced in Pakistan is through non-renewable imported fossil fuels. Therefore, it results in an elevated cost per kW-hr along with a huge impact on environmental degradation. To address these issues, this study focuses on devising a novel Hybrid Energy System (HEEs) to manage electrical energy consumption for agricultural irrigation and remote locals in the Khyber Pakhtunkhwa (KPK) province having limited electrical supply. The required water volume for the proposed irrigated land is determined by utilizing CROPWAT 8.0 and CLIMWAT 2.0 software tools. On-grid Hybrid Energy System (HES) is presented due to the advantages of high reliability and cost-effectiveness over conventional single-source systems. Using the Hybrid Optimization Model for Electric Renewables (HOMER), the research performs the techno-economic analysis of various HES configurations including Hydro, Solar, Wind, and Grid. The financial feasibility of the proposed system is evaluated using the HOMER software. The findings reveal that HES with the integration of hydro, solar, wind, and grid has an economical Cost of Energy (COE) equal to \$0.006274. In contrast, other combinations, such as solar, wind, and grid possess COE of \$0.0252, and solar, micro hydro, and grid, which result in a COE of \$0.0267 respectively.

Keywords: Wind Turbine, DFIG, LVRT, Fault Analysis, Lightning Studies, Protection.

CHAPTER 1: INTRODUCTION

1.1 Background

According to research from The International Energy Agency (IEA), about 30% of people in towns and villages don't have electricity. Right now, a big part of the world's people lives in Africa below Sahara and South Asia [1]. The IEA says that if we don't use new ideas to make electricity better, 16% of the world will still not have power by 2030. Mostly people in Africa and South Asia would be affected [2]. Pakistan's energy sector is now facing big problems. Even though the world is moving towards different ways to make energy, Pakistan still uses a lot of methods that are not renewable. Figure 1.1 below shows energy outlook of Pakistan for the fiscal year 2017-18.

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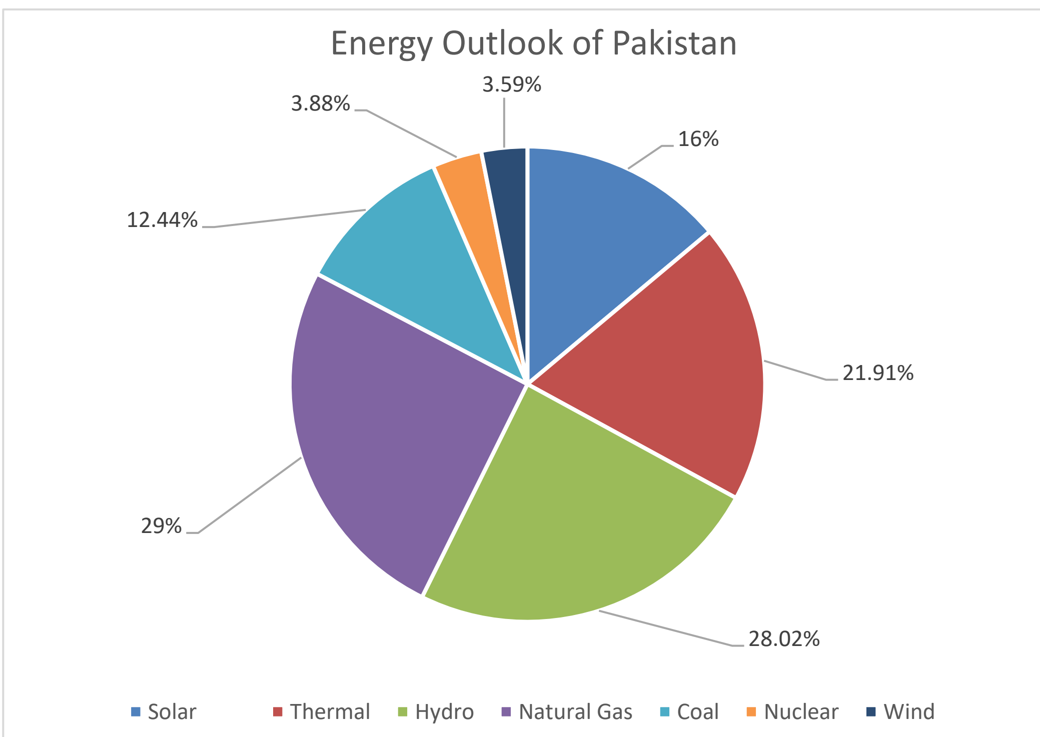

Figure 1.1: Energy Outlook of Pakistan for the year 2017-18

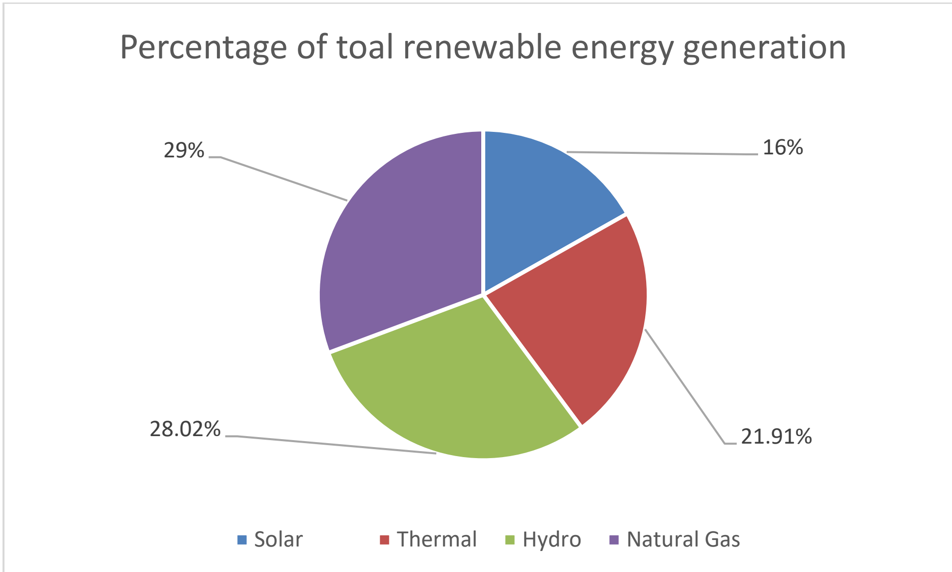

Figure 1.2: Pakistan Renewable energy generation in 2022.

When we say rural electrification, it means giving electricity to houses or towns in faraway places. Electrification of villages is usually hard for the following reasons [4].

- Found in far-off and secluded places.
- Experience severe climatic conditions.
- Spread out people with few individuals living close together.
- Low load density.
- Limited revenue generation.

Countries that are still growing often give huge importance to providing electricity in the countryside, but a major problem is choosing the right technology for this task. Picking a certain type of technology for lighting up rural areas is based on traits of the group or family living in that area. We also need to think about things like how heavy the load is, how far it is from a big power supply network and if there are other energy options. We must also consider social factors such as economics, technology maturity level amongst others before choosing what method could work best for providing electricity in rural areas that we target.

1.2 Problem Statement

Having a smooth supply of electricity is important for meeting basic needs in life such as food, health care, schooling, and fairness. This also helps keep our surroundings nice and steady. Unfortunately, the aim of making sure everyone has access to energy is not yet reached.

In Pakistan, one major issue for its economy is not having enough power to meet what people need. The difference between what's needed and what is available keeps growing more. But Pakistan has many renewable energy sources, and it's necessary to move towards cleaner, greener choices [5]. Burning fuels like coal and oil makes the air dirty. This can harm people's health, as well as hurt nature. It leads to issues such as fires, storms, and makes farming harder. This impacts how we live every day.

Pakistan has a big problem with not having enough power. This means that many parts of life are affected and about 40,000 villages do not have electricity. According to the World Energy Outlook (WEO) in 2015, about one out of every three people living far away from cities and towns in Pakistan still cannot use electricity. Integrating multiple resources in these villages would cost a lot of money. The chart in figure 1.4 displays the amount of power produced, the need for it, how much is available and not enough for different years.

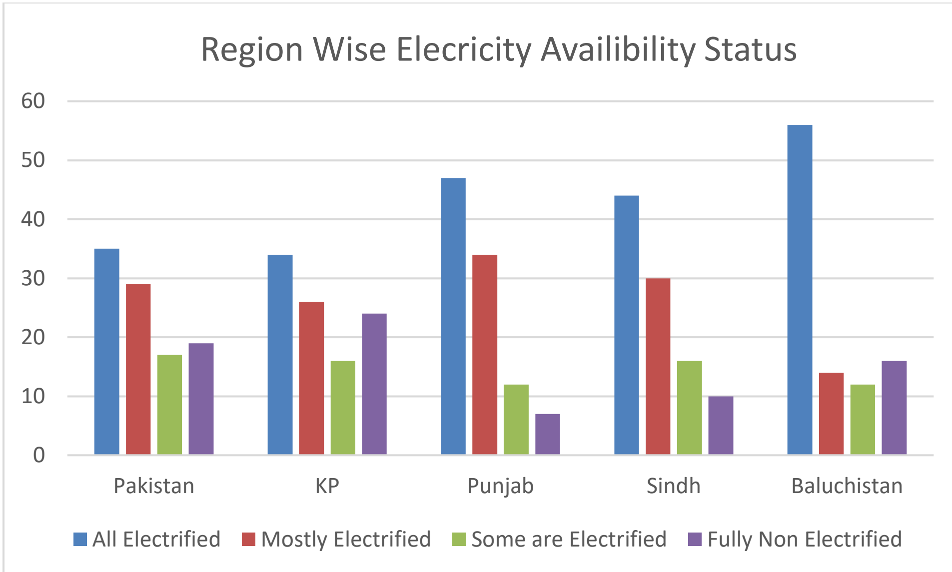

Figure 1.3 : Region wise electricity availability status of Pakistan

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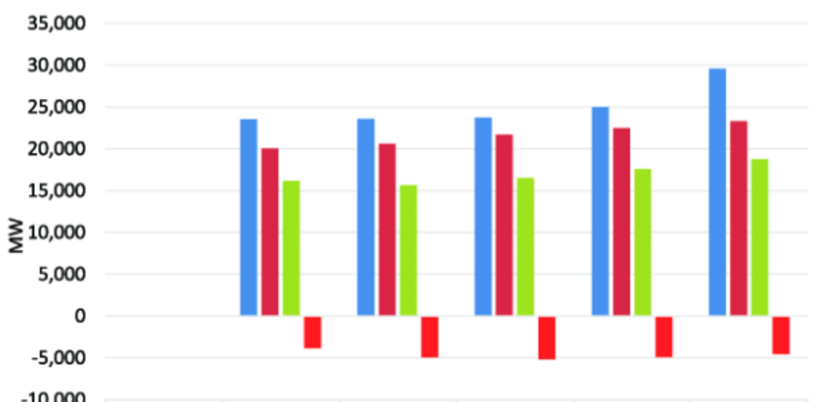


	FY	2013-14	2014-15	2015-16	2016-17	2017-18
Installed Capacity		23,531	23,579	23,718	25,000	29,573
Demand		20,012	20,592	21,701	22,457	23,301
Supply		16,170	15,632	16,500	17,551	18,742
Shortfall		-3,842	-4,960	-5,201	-4,906	-4,559

Figure 1.4: Region wise electricity availability status of Pakistan

On the positive side, Pakistan has many natural resources of clean energy like water, solar, and wind. These could fix the energy crisis being faced by Pakistan since long [6]. For example, we could have over 100 gigawatts from dams on rivers. We can also use a lot of sun power (2900 total) and wind energy (125 gigawatts) plus, there's potential for about 6-gigawatt capacity using plant stuff as fuel source. But, even with this, only a little bit of power - just hundreds of megawatts - comes from these places. So, getting electricity to rural areas by using these clean energy sources seems like the best option [7].

1.3 Objective

The aim of this study is to give integrate multiple renewable energy resources in far-off and small villages in Pakistan that have either no supply of power or facing long hours of loadshedding. It will combine different types of sources such as wind, solar, and micro hydro energy sources. The study will focus on the following objectives:

- Collect and study information to find possible places in the country, using these details for choosing them.
- Make a blended system plan for chosen rural place using HOMER software.
- Doing a cost-benefit study of the planned mixed system.

CHAPTER 2: LITERATURE REVIEW

For many years, photovoltaic (PV) systems have been changing and improving. This is because people keep looking for ways to make them more efficient, cost less money and be useful in lots of different places[8]. Getting better at making things with perovskite for solar panels and improving the way they're made have greatly increased how well PV cells work[9]. These improvements, along with the use of high-tech tracking devices have made a big difference. They've helped to make solar energy more powerful and dependable for giving electricity[7].

One big improvement in solar power technology is the use of perovskite-based sun cells. Perovskite stuff looks very good to reach high change rates at a lower cost than usual solar cells made from silicon[10]. Scientists are working hard to find better ways and tools for making perovskite solar cells bigger and more stable so they can sell them on a large scale. This way of study could really change the solar business. It will give a cheaper and better option than old PV methods[11].

The link of PV systems to smart grids is a big step forward in making power distribution more stable and effective. Smart grids use smart systems to manage the flow of electricity[12]. They help match solar power, which can be sporadic. In real time, changes are made based on things like weather and how much electricity is being used. This helps to use solar power at its best and keep the grid steady. Scientists are working hard to make smart grids work better and easier[1]. They create clever computer programs and ways of managing the grid to help it all join smoothly.

Storing energy is very important for dealing with the unpredictability of sunlight power. While PV systems make electricity when there's sun, energy storage things like better batteries keep extra power for use in times of low light[2]. This is very important for providing a steady and trustworthy supply of power. This type of study is about making energy storage methods better, longer lasting, and cheaper. Improvements in battery science, big storage systems and small local solutions help make a stronger energy system that can change easily[13].

The cost-effective use of solar power systems is an ever-changing field. Many studies investigate how to get the lowest price for each unit of electricity (cost per kWh)[14]. LCOE shows the total cost of making electricity in a solar system over its whole life. Factors like putting it together, looking after and running matter too. The cost of solar power keeps going down because new tech improvements, big factories making more for less money and support from the government[6]. This cut in costs makes solar power systems better compared to normal energy sources. This helps them be used more often and connected with big electricity grids for everyday use.

Rules and programs that offer rewards are important for making sure solar power systems can work well in the money part of economy[15]. Governments all over the world are making plans to support using clean energy. They give money help, discounts and rules backing for this purpose. Feed-in tariffs, tax credits and renewable portfolio standards are examples of policy tools meant to quickly increase PV system use[8]. The mixing of advancements in technology with helpful rules makes a good place for the solar business to grow. This pushes new ideas and competition between businesses[16].

Wind turbines (WT) are another area in renewable energy studies. They use the moving power of wind to make electricity. The path of study in this area concentrates on complex tech advancements to get the most energy and keep costs low[17]. Optimizing how knives look, making hubs taller and finding new materials to use are the main things being studied. These changes help make wind turbines work better and more trustworthy, making wind power a good choice for electricity[18].

The growth of wind farms far from the shore has become a main topic in studying wind power. Offshore places have better and steady wind speeds, so it's not as changeable as onshore wind farms[19]. Also, wind farms in the sea help with space problems and possible disagreements with nearby people. Building wind farms out at sea is not easy. It can cost more, it's hard to organize and they are in a strong ocean no matter what happens around them[10]. Studies in this field aim to solve these problems with better offshore wind turbine technology, creative base designs and helpful keep up methods.

People are still working hard on problems about putting up, fixing, and making windmills work smoothly with the electricity network[18]. Checking and predictive maintenance methods are very important to make sure wind turbines work often and just right. Big sensors, smart data looking and learning machines are used to find problems early. This lets us do maintenance before they get bad so there's less time when things stop working properly[20]. Further study on how to connect wind power to the grid looks at ways of dealing with changes in wind energy and making our electricity systems more secure.

Small-scale systems that use the power of moving water are very important for local energy answers. They mostly help places without easy access to electricity[21]. These systems give a steady and long-lasting way of making electricity for people living close to water sources. Study of small waterpower shows careful planning, using things like how much water flows and the height difference[22]. This research also looks at effects on nature too. These efforts use good ways that last, with people always studying to measure and lessen the harm on nature caused by small-scale waterpower projects[21].

A big topic of study in small power from water is making turbines work well. Different kinds of wheels, like crossflow and Kaplan turbines, are investigated to get the most energy from different water flow rates[23]. Making turbines work better helps to improve the total power and money worth of small hydropower systems. Further studies are looking into new materials and ways of making things to lessen harm on the environment and make micro hydro equipment last longer[24].

It's important to think about the effect micro hydropower projects have on the environment, especially in areas where nature is sensitive[25]. Study attempts try to judge and lessen the effect on water life systems, like fish routes, water quality and possible place damage. The use of good plans, like safe fish-turbo designs and complete nature checks is very important for making sure that small hydropower projects last a long time[26].

Going beyond the small details, micro hydropower projects really help make power reach rural areas. In many far or not well-served places, small hydropower systems help a lot[27]. They give electricity that can keep going for a long time and is right there where people live[28]. Community-based plans are looked at, focusing on the active part locals play in making plans for small hydroelectric power projects. This includes setting it up and looking after what's been made. Being accepted and cost-effective are important for a project's success[29]. This shows that talking with local people and making solutions just right for their needs is very necessary.

In short, all the work groups in solar power, wind energy and small water wheels together show a complete way to solve different problems. These involve making technology better, being able to pay for it, not hurting the environment and getting people to agree[28]. Together these things promote renewable energy so that they can easily fit into how everyone around the world uses power. As the world moves more to green energy, work and study done will be very important[30]. It will help make renewable energy tech better while making sure people from all overuses it a lot.

CHAPTER 3: RESEARCH METHODLOGY

3.1 Introduction

The goal of this research is to develop and provide analysis optimized on grid hybrid PV, Solar, Wind, hydro-grid models for a rural region in Pakistan which will solve the problem of energy crisis which is rapidly increasing with increase in demand. Focus is placed on the use of renewable resources, such as wind, solar and micro hydro for providing local energy solutions without damaging the environment. Statistical data on unelectrified villages per provinces were subject to study as well, and there was a keen interest in the development of sustainable energy alternatives.

Table 3.1: Access to energy-related infrastructure, by Province.

Area	KP	Punjab	Sindh	Baluchistan
Rural	605	621	16,198	3496

The statistics in Table 3.1 show that Sindh and Baluchistan have the highest number of unelectrified villages with total villages alone making up 77% of country's undeveloped village population. 621 of the villages remain unelectrified despite its relatively good electrical connectivity ratio. Madad Khan Banda village in Khyber Pakhtunkhwa has been chosen for this research. 1 It is easy to see the reason for this decision – Madad Khan Banda has a very poor electricity supply, being subjected to more than 13 hours of load shedding.

3.2 Solution Design for Electrical Supply to the Marginalized Communities

When addressing the project's objectives, solution design starts with a comprehensive problem evaluation defining the need for reliable and sustainable power solutions, especially in places where grid access is limited. Then, suitable sites are carefully picked regarding geographical and climatic conditions. HOMER PRO Software is then used for overall resource evaluation which includes analysis of solar radiation, wind speed and other renewable energy sources. Further on, the user load calculations are made to assess energy consumption trends to meet specific demands. HOMER PRO helps design such a system where renewable sources, energy storage and back up facilities are interfaced. A techno-economic analysis is performed, including capital and operating costs to optimize the system configuration for cost effectiveness. The results and discussions cover the main findings, trade-offs, implications that lead to recommendations as well as considerations for scalability and applicability of this project in similar projects.

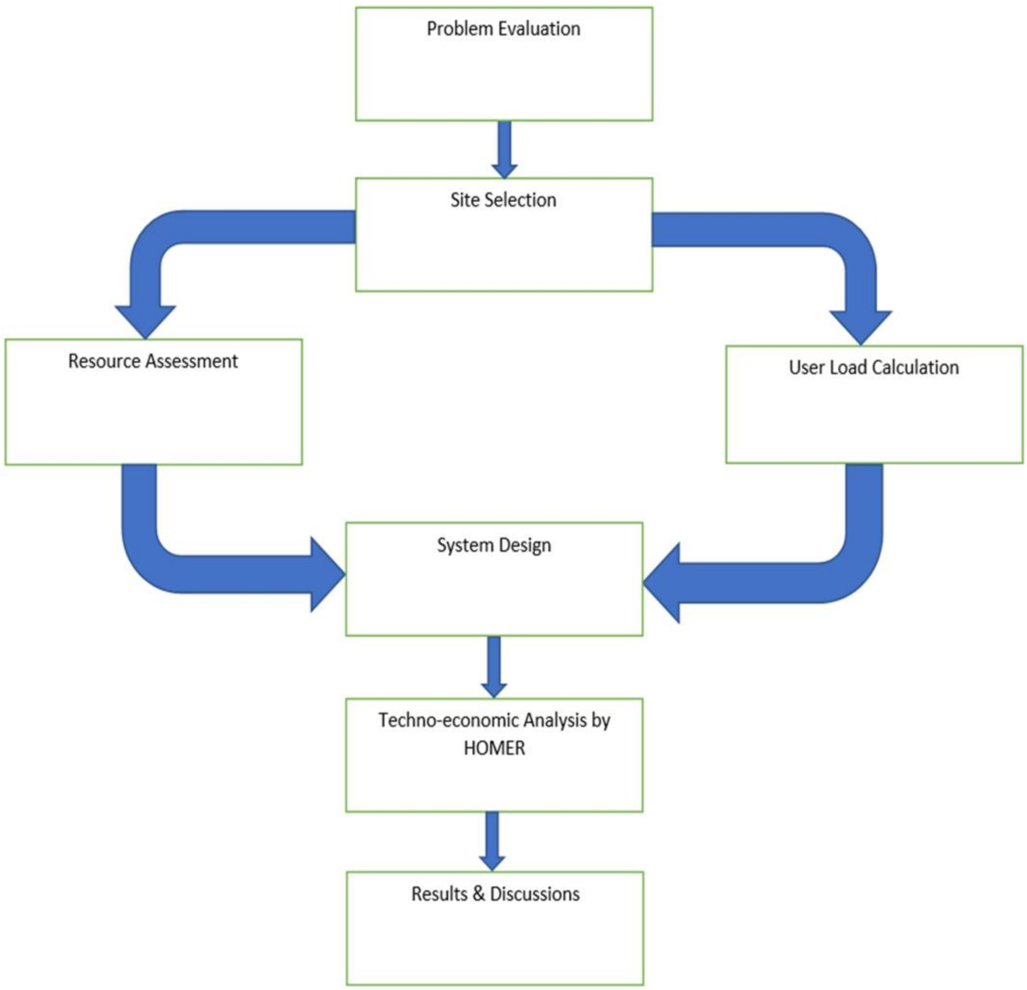


Figure 3.1: Methodology of Designing Hybrid System Using HOMER Pro.

3.3 Problem Evaluation

Begin by clearly defining the problem your project aims to address. This could be the need for a reliable and sustainable power solution in a specific location, such as a remote area with limited access to the grid.

3.4 Site Selection

Identify and evaluate potential sites for the implementation of your power solution. Consider factors such as geographical location, climate, topography, and accessibility. The goal is to choose a site that aligns with the project's objectives and resource availability.

3.5 Resource Assessment

Utilize HOMER PRO Software to assess the available resources at the chosen site. This includes solar radiation, wind speed, and any other relevant renewable energy sources. Accurate resource assessment is crucial for designing an effective and efficient power system.

3.6 User Load Calculation

Analyze the energy consumption patterns of the users at the selected site. Consider both residential and any other relevant loads. This step involves understanding the electricity demands, load profiles, and peak usage periods to ensure the designed system meets the specific needs of the users.

3.7 System Design

Based on the resource assessment and user load calculations, use HOMER PRO to design an integrated power system. This may involve combining renewable energy sources like solar and wind, along with energy storage solutions and possibly a backup generator. Ensure the system can meet the energy demands reliably.

3.8 Techno-Economical Analysis by HOMER

Conduct a thorough techno-economic analysis using HOMER PRO Software. This involves assessing the costs associated with implementing and maintaining the proposed power system over its expected lifetime. Consider capital costs, operational costs, and potential revenue generation if applicable. HOMER PRO's optimization capabilities can help find the most cost-effective solution.

CHAPTER 4: DATA ANALYSIS

As such, Madad Khan Banda is a perfect spot for the grid-connected hybrid renewable energy project as it combines geographical elements with environmental and socio-economic implications. The site location strategy is in line with the overall objectives of the project to build a resource-efficient, self-reliant energy system while at the same time developing socio economic growth as well as optimal use of resources within that selected community.

4.1 In-Depth Load Analysis

A meticulous exploration of the load dynamics for the grid-connected hybrid renewable energy project revealed a comprehensive classification into two pivotal categories: residential and water pump load. The residential load was analyzed in a multi-disciplinary manner, which included site visits and comprehensive surveying. Comprehensive results as outlined in Table 4.1.

An in-depth analysis was conducted as follows to determine the load demand for water pump component, which is an essential part of both irrigation and domestic water needs. The first stage involved careful computation of water needs for irrigation purposes as well as domestic use. 70 liters/person – a daily necessity for drinking water resulted in the overall need of 8,400 liters (or equivalently eight and point four cubic meters) per day if there are thirty households each with family components that numbered at about four individuals.

For irrigation planning, two advanced software tools – CROPWAT 8.0 and CLIMWAT 2.0 – were employed in this project as well. These applications required specialized input data such as temperature and average rainfall, among other relevant measures specific to the proposed site. After entering this data for two major crops – wheat and maize, the result showed that while 96.25 m3 day was required per day to irrigate wheat crop again, whereas on daily basis more water amounting at a total of 120 m3 was consumed by all plants belonging to Maize family across its entire lifecycle/growth thus taking average.

Table 4.1: Residential Load Calculation.

No of houses	**Light load in Wh**	**TV load in Wh**	**Refrigerator load In Wh**	**Fan load in Wh**	**Electric iron load in Wh**	**Mobile charger load in Wh**	**Summer Load in Wh**	**Winter Load in Wh**
1	4*15*14=840	1*80*4=320	1*250*15=3750	3*80*10=2400	1*1200*30=3600	1*6*2=12	5.536	2.768
2	4*15*12=720	NA	1*250*14=3500	2*80*12=1920	1*1200*30=3600	2*6*5=60	5.852	2.666
3	4*15*12=720	2*80*4=640	1*250*15=3750	4*80*10=3200	1*1200*30=3600	2*6*5=60	6.832	3.412
4	4*15*14=840	1*80*2=160	1*250*16=4000	3*80*10=2400	1*1200*30=3600	2*6*3=36	5.853	2.58
5	4*15*8=480	1*80*4=320	NA	2*80*12=1920	NA	1*6*4=24	3.2	1.55
6	5*15*8=600	1*80*2=160	1*250*15=3750	2*80*12=1920	NA	1*6*4=24	3.94	1.53
7	6*15*6=540	1*80*4=320	NA	2*80*8=1296	NA	1*6*2=12	2.992	1.56
8	5*15*6=450	NA	NA	2*80*8=1296	NA	2*6*3=36	2.0167	1.03
9	4*15*8=480	NA	NA	2*80*8=1296	NA	2*6*3=36	1.576	0.716

10	4*15*12=720	1*80*2=160	1*250*14=3500	3*80*10=2400	1*1200*30=3600	1*6*4=24	3.94	1.57
11	2*15*8=240	NA	NA	2*80*12=1920	1*1200*30=3600	1*6*4=24	1.4	0.75
12	4*15*8=480	NA	NA	2*80*12=1920	NA	1*6*4=24	2.152	1.75
13	24*15*5=1200	2*80*4=640	2*250*14=7000	2*80*14=2240	1*1200*30=3600	3*6*4=72	6.567	3.48
14	24*15*9=3240	2*80*4=640	2*250*14=7000	5*80*14=9600	1*1200*30=3600	3*6*4=72	6.832	3.423
15	4*15*10=600	1*80*2=160	1*250*14=3500	2*80*14=2240	1*1200*30=3600	1*6*4=24	3.94	1.98

This load assessment carefully balances out the immediate energy needs of residential units and at the same time, goes into details about water demands which are imperative for sustaining agricultural besides domestic activities. Use of such advanced software tools helps to increase the precision level in analysis making sure that it is fine-tune for any community need and proposed site peculiarities.

4.2 Load Division

The load was divided into two main categories: residential and water pump. Estimating the residential load formed part of this process and involved site visits where surveys were taken to determine what number, kinds of electrical appliances are there with their wattage as well as how many hours do they run on average. Assessing the water pump load was initially based on calculating water demand for irrigation and domestic use. 70 liters per person for drinking water meant a daily requirement of 8,400 liters (or 8.4m3) per day of the community made up from households numbering thirty with four individuals each. Irrigation assessment used two software tools CROPWAT 8.0 and CLIMWAT2 .0, which require input records of average temperature, rainfall, among other site-specific parameters The stream of input data produced the following outcomes in accordance with software.

Table 4.2: Comprehensive Data

Month	**Decade**	**Stage**	**Kc coeff**	**ETc mm/day**	**ETc mm/dec**	**Eff rain mm/dec**	**Irr. Req. mm/dec**	**Irr. Req. m/day**	**for 20-acre land (80937.1m^2)**
Oct	2	Init	0.3	1.14	6.9	11.5	0	0	0
Oct	3	Init	0.3	1.02	11.2	14.4	0	0	0
Nov	1	Init	0.3	0.9	9	8.4	0.6	0.00006	4.856226
Nov	2	Deve	0.38	0.98	9.8	3.5	6.3	0.00063	50.990373
Nov	3	Deve	0.65	1.51	15.1	2.5	12.7	0.00127	102.790117
Dec	1	Deve	0.93	1.92	19.2	1.2	18	0.0018	145.68678
Dec	2	Mid	1.13	2.04	20.4	0	20.4	0.00204	165.111684
Dec	3	Mid	1.14	2.03	22.3	0	22.3	0.00223	180.489733
Jan	1	Mid	1.14	2	20	0	20	0.002	161.8742
Jan	2	Mid	1.14	1.98	19.8	0	19.8	0.00198	160.255458
Jan	3	Late	1.03	1.97	21.7	0.1	21.6	0.00216	174.824136
Feb	1	Late	0.74	1.55	15.5	0.7	14.7	0.00147	118.977537
Feb	2	Late	0.45	1.04	10.4	1.1	9.3	0.00093	75.271503
Feb	3	Late	0.3	0.79	0.8	0.1	0.8	0.00008	6.474968
									total m^3/day=96.25

Month	**Decade**	**Stage**	**Kc coeff**	**ETc mm/day**	**ETc mm/dec**	**Eff rain mm/dec**	**Irr. Req. mm/dec**	**m/day**	**for 20 acres (80937.1m^2)**
Jul	3	Init	0.3	2.04	2	1.5	2	0.0002	16.18742
Aug	1	Init	0.3	1.92	19.2	19.9	0	0	0
Aug	2	Deve	0.3	1.83	18.3	23.2	0	0	0
Aug	3	Deve	0.48	2.75	30.2	17.4	12.8	0.00128	103.599488
Sep	1	Deve	0.75	4.05	40.5	9.5	31	0.0031	250.90501

Sep	2	Deve	1	5.13	51.3	4.2	47.1	0.00471	381.213741
Sep	3	Mid	1.19	5.56	55.6	3.9	51.7	0.00517	418.444807
Oct	1	Mid	1.2	5.07	50.7	3.9	46.9	0.00469	379.594999
Oct	2	Mid	1.2	4.56	45.6	2.9	42.7	0.00427	345.601417
Oct	3	Mid	1.2	4.07	44.8	3.2	41.5	0.00415	335.888965
Nov	1	Late	1.09	3.28	32.8	3.5	29.3	0.00293	237.145703
Nov	2	Late	0.81	2.11	21.1	3.6	17.5	0.00175	141.639925
Nov	3	Late	0.53	1.24	12.4	4.8	7.6	0.00076	61.512196
Dec	1	Late	0.36	0.75	1.5	1.3	1.5	0.00015	12.140565
									total m^3/day=120

The power equation is expressed as P_pump = (ρgHQ)/η …….2, where:

- ρ represents the density of water (1000 kg/m^3),
- g is the gravitational acceleration (9.8 m/s^2),
- H is the height in meters (55 m in our case),
- Q denotes the water flow in m^3/hr (19.4 m^3/hr in our case, considering 6 sunny hours).
- By applying equation 2, the calculated power is 6.05 kW.

In comparison, the average residential energy consumption is 239 kWh, while the water pump demonstrates an average energy consumption of 145.37 kWh.

This method is so detailed, that it builds a strong frame for sustainable energy solution consistent with the varied requirements of identified population ensuring resource utilization which encourages environment awareness and community aware development.

Table 4.3: Total Summer and Winter Energy Consumption

Total summer load in kWh		Total winter load in kWh
for 15 houses	158	81
Per house	10.55	5.4
For 30 houses	316	162

Load demands of the water pump in grid-connected hybrid renewable energy project are determined as P_pump = (ρgHQ)/η where ρ is density of liquid H2O , assumed to be 1000kg/m3 g is gravitational acceleration that has a constant value, which may vary with altitude but considered equal for practical use and it' So by using this equation the power requirement for water pump is carefully calculated. In our case, the estimated power output is 6.05 kW that will provide an accurate understanding of how much energy a water pump in this project needs. This calculation does not only clarify the technical nuances of how this system works, but it also plays an essential role in overall energy planning and optimization for operating a hybrid renewable energy project sustainably.

On average, residential energy consumption stood at 239 KWhr, while the water pump exhibited an average energy consumption of 145.37 KWhr.

4.3 Evaluation of Energy Sources

a. Solar irradiance

Essential data for the grid-connected hybrid renewable energy project relevant to solar systems was collected with special care via Homer, modern software that imports from NASA Surface Meteorology and Solar Energy database. This database is an aggregate of information about the sun, which provides critical insight into measurements of irradiation that are crucial in determining success for this project. This process entailed that geographic coordinates of the identified project site were plugged into Homer to obtain relevant solar data. Most notably, the geographical area in question registered its highest ever solar irradiation in June, recording an impressive magnitude of 7.880 kWh/m^2day. Moreover, a computed average solar irradiation value of 5.31 KWhr/m2day gives its knowledgeable and detailed context on constant solar exposure the site has all year round). The daily solar radiation intensity, measured in kilowatt-hours per square meter per day are shown by Figure 4.1 providing a visual tool to better understand how the dynamics of that energy change with time. This data can be an important pillar for efficient energy planning allowing the project to capture all the possible solar potential that is available at its designated location to maximize electricity generation.

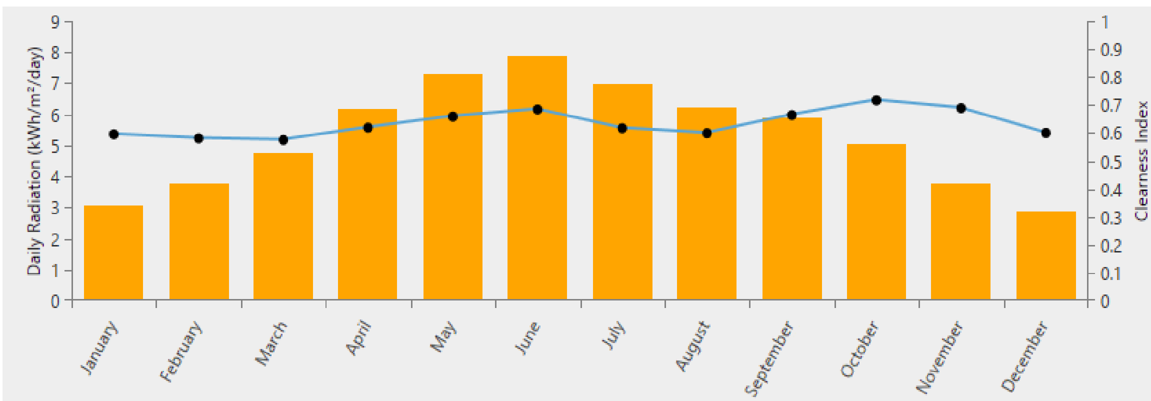


Figure 4.1: Daily radiations in kWh/m^2/day

b. Wind Resource

HOMER software advanced functionalities made it possible to carry out the determination of wind velocity in meters per second m/s for grid-connected hybrid renewable energy project. This software easily combines information using NASA Surface Meteorology and Solar Energy Database to offer a more complete and accurate evaluation of the wind speeds necessary for success in this project. Measured data was carefully recorded at a height of 50 meters to accurately reflect wind phenomena. Visually, Figure 4.2 represents the wind speed profile in the selected geographical region to illustrate a maximum velocity of 8.260 m/s and an average one coming at around 6.58 m/s.

It is interesting to note that HOMER uses power law formula for calculating the wind speeds at turbine hub height which plays an important role when assessing possible energy generation from resources of Hence this methodology ensures that the values of wind speed obtained are matched with the operational parameters of a given wind turbine. Figure 4.2 is a comprehensive depiction of wind characteristics that play an integral role in optimizing the design and performance of the energy component within hybrid system. This data-centric approach empowers the project to maximize wind energy capabilities for use at the selected site, helping significantly enhance overall efficiency and sustainability of this renewable energy initiative. [31].

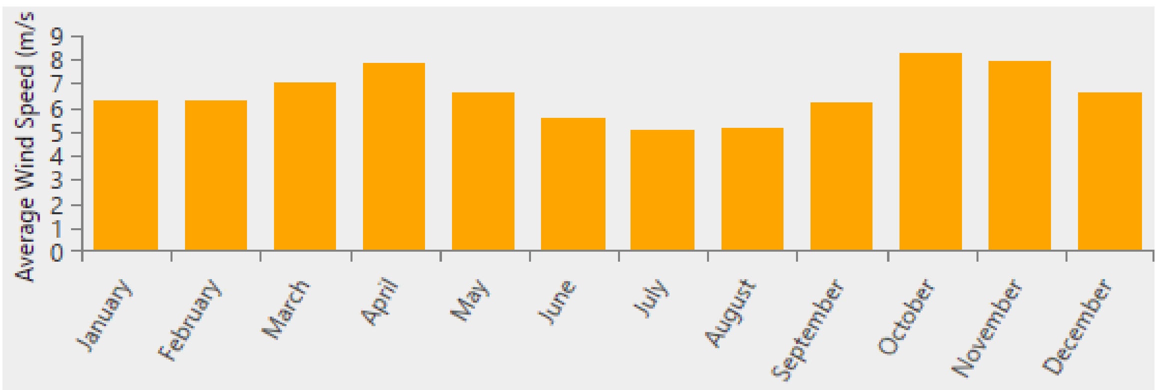


Figure 4.2: Average wind speed in m/s

c. Micro Hydro

Hydropower is one of the main giants in terms of renewable energy sources and utilizes natural hydroelectric power that rests within waters at altitude. This thrust becomes the cause for rotational force of an electrical generator leading to generating electric energy. The whole process represents the beauty of harmonizing with nature to utilize her energy without harming it in any way.

In the geographical area defined for implementation of a grid-connected hybrid renewable energy plan, it can be noted that water within canal runs continuously and consistently year-round unless briefly interrupted during winter months from December to February as shown in Figure 4.3. Hydropower is significant as it harnesses the potential gravitational energy of water which points to an active interplay between elevation and flow.

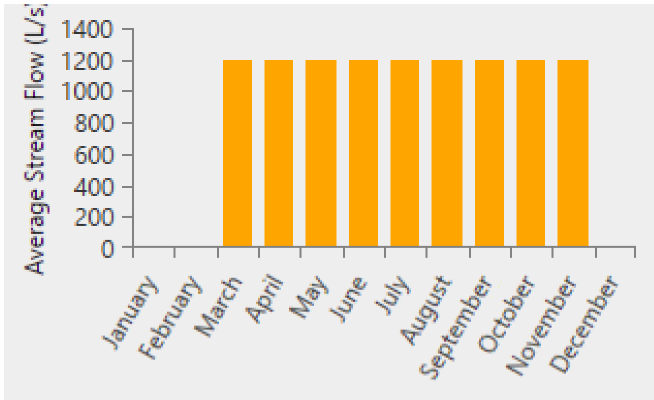


Figure 4.3: Average stream flow in litters/sec

Hydropower is based on the fundamental pattern that the stored kinetic energy of water at a higher altitude can be effectively harnessed to rotate impeller. In turn this movement acts as a catalyst for the generation of electricity and thus demonstrates how there can be harmony between nature's forces.

Knowledge about the cyclical nature of water availability is very important, particularly in regions characterized by seasonality. This knowledge becomes a foundation for improving the efficiency of the hydropower system at large within the chosen site. This project is part of the broader story regarding sustainable and environmentally friendly energy solutions by taking advantage of the ceaseless currents associated with water flow to make sure there will always be reliable and constant access to renewable resources.

4.4 System Designing

At the core of this comprehensive hybrid project lies a dynamic integration of four distinct energy sources: Each of the sources unique contributes a part to this project's energy portfolio; however, collectively they make up an amazingly robust and flexible system. The reason to do this is strategic, as the grid component serves as one of the most vital components in overall energy management strategy.

This new framework serves a dual purpose of the grid. First, it serves as a means for redirecting the surplus energy produced by the hybrid system into that whole electrical grid. This is achieved using green meters, which create a sustainable mechanism that can redistribute surplus energy in an efficient manner. This grid integration strategy eliminates the need for expensive battery storage systems that would be required if this alternative were utilized, reducing energy storage costs, and improving overall system efficiency.

Second, taking advantage of the grid connection not only reduces the requirement for complicated battery solutions but may also have financial advantages. The option to feed surplus energy back into the grid is also possible that would lead to a reduction in general costs for the project, which could make it economically viable over time. Moreover, in some cases this symbiotic relationship with the grid might even be profitable through deals made out with other notable bodies such as WAPDA.

In other words, incorporating the grid component of this hybrid energy project simply showcases a well thought out strategic approach to sustainable and cost-effective provision of power. It turns the system into a dynamic and adaptive energy ecosystem, where not only the production of energy and storage is optimized but also an interaction between the larger part of this infrastructure builds up two-way relationships that in general leads to sustainability efficiency as well as possibly even making money. The famous equation used for calculating electrical power for hydropower plants is:

The calculation of power generated by the mini hydro power plant is based on the formula.

$$P\_hydro = \eta \rho g Q H,$$

where η represents the efficiency of the hydropower plant (75% in our case)

ρ is the density of water (1000 kg/m^3),

Q denotes the water flow in meters per second (1.2 m/s in our case)

H signifies the height of the water fall in meters (2 m in our case)

Substituting these values into the equation yields a comprehensive understanding of the power output potential. Therefore, utilizing equation 2 and considering the specified efficiency of the mini hydro power plant as 75%, the calculated power output stands at 16 kW. This numerical representation encapsulates the plant's capacity to efficiently convert the kinetic energy of flowing water into a substantial electrical power output, elucidating the operational dynamics of the mini hydro power plant within the broader context of the renewable energy project.

4.5 Solar PV System

In the rollout of this renewable energy project, the selection of photovoltaic (PV) technology entails using polycrystalline PV panels. These panels were selected based on their proven efficiency and reliability. As a result, the sophisticated functions of Homer were utilized in conducting an intensive study on different capacities for solar panels to identify what configuration would be most cost-effective. Recognizing that solar panel performance depends closely on radiation and temperature, an innovative idea emerged. The use of Maximum Power Tracking Point (MPPT) technology dynamics the system. This novel technology is constantly able to monitor and adjust the operational point on the PV curve, allowing for these panels to always run at their purest operating capacity. This is known as MPP maximum power point. This approach ensures that the solar PV system utilizes all available resources of sunshine thus enhancing its efficiency. MPPT incorporation is a sign of the project’s dedication to improving generation efficiency and exploiting all solar resources.

Table 4.4: Different parameters of Solar PV

S. No	Parameter	value	unit
1	Capital cost	660	$/kw
2	Replacement cost	660	$/Kw
3	O&M cost	10	$/year
4	Lifetime	25	year
5	Derating factor	80	%

6	Rated power	250	W
7	Short circuit current	8.76	A
8	Open circuit voltage	37.5	V

4.6 Wind Turbine

The proposed system of power generation from wind obeys a crucial characteristic – the output of such produced energy is proportional to cubes of such intended wind speed. 3 kW model with a distinctive identifier FT- 3000 and having the distinguishing feature of being strong to be used for this venture, is chosen as wind turbine in such manner after careful consideration trying to obtain maximum benefit from it through power generation. Table 4.5 provides a comprehensive representation of the parameters defining the proposed wind power plant, including key specifications such as turbine model used rotor diameter and power capacity. The selection of the FT-300. wind turbine, including focus on its most crucial parameters also shows that this project aims at converting energy from wind in an efficient manner which will add a significant percentage to global renewable output.

Table 4.5: Different Parameters of Wind Turbine.

S. No	Parameter	Value	SI Unit
1	Capital Cost	890	$
2	Replacement Cost	600	$
3	O&M Cost	100	$/year
4	Lifetime	20	years
5	Model	FT-3000L	-
6	Cut in speed	2.5	m/s
7	Rated wind speed	11	m/s
8	Rated voltage	48	v

9	Rated Power	3000	W
10	Rotor diameter	3380	mm
11	Number of blades	3	
12	Approx. weight	70	kg

4.7 PV Converter

The converter component integrated in the HOMER software framework is very versatile, playing a central double role, acting as rectifier and an inverter. This complex element plays a crucial role in the energy conversion process, mainly responsible for converting DC power produced by solar panels into AC compatible with load specifications. This converter module has been operating for more than 15 years due to its strong design and steady operation. 90 percent associated efficiency rating of this converter unit is set to enable smooth energy conversion where operational efficiency will remain high throughout its specified lifespan.

Table 4.6: Model, Watts, Price and Links of Hybrid Inverters in Pakistan

Model	Capacity (kW)	Price (PKR)	Retailer Link
MIN 2500TL-XH	2.5	70,000 - 75,000	https://solarshop.pk/product-tag/growatt-solar-inverter-in-pakistan/
MIN 3000TL-XH	3	75,000 - 80,000	https://www.pricesurvey.pk/growatt-solar-inverter-price-in-pakistan/
MIN 4000TL-XH	4	85,000 - 90,000	https://www.growattpk.com/on-off-grid-4g-hybrid-4000-24.php
MIN 5000TL-XH	5	95,000 - 100,000	https://pricecity.com.pk/growatt-5kw-5000-mtl-s-hybrid-inverter.html
MIN 6000TL-XH	6	105,000 - 110,000	https://www.growattpk.com/revo-on-off-grid-6000-48.php
MIN 7000TL-XH	7	115,000 - 120,000	https://www.pricesurvey.pk/growatt-solar-inverter-price-in-pakistan/

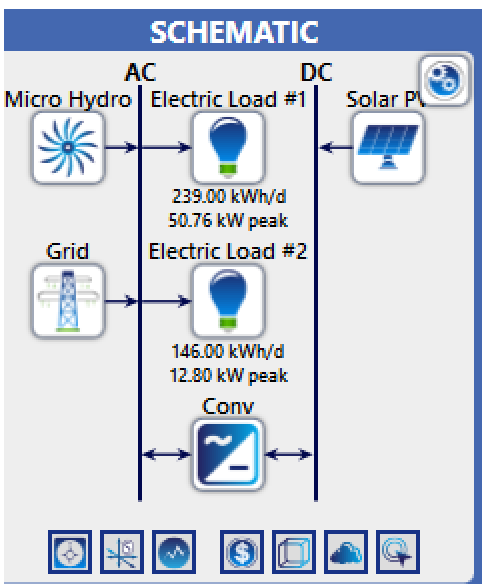
MIN 8000TL-XH	8	125,000 - 130,000	https://www.pricesurvey.pk/growatt-solar-inverter-price-in-pakistan/
MIN 10000TL-XH	10	140,000 - 145,000	https://www.solarprice.pk/product/growat-10-kw-solar-inverter/
MIN 12000TL-XH	12	155,000 - 160,000	https://www.pricesurvey.pk/growatt-solar-inverter-price-in-pakistan/
SPF5000LT	5	230,000 - 240,000	https://pricecity.com.pk/growatt-5kw-5000-mtl-s-hybrid-inverter.html
SPF3000LT	3	180,000 - 190,000	https://www.growattpk.com/
SPF10000LT	10	310,000 - 320,000	https://www.solarprice.pk/product/growat-10-kw-solar-inverter/
LVM 5000-TL	5	250,000 - 260,000	https://solartrade.pk/product-category/inverter-ups/on-grid/growatt/
LVM 6000-TL	6	280,000 - 290,000	https://solartrade.pk/product-category/inverter-ups/on-grid/growatt/
LVM 8000-TL	8	330,000 - 340,000	https://solartrade.pk/product-category/inverter-ups/on-grid/growatt/
LVM 10000-TL	10	380,000 - 390,000	https://solartrade.pk/product-category/inverter-ups/on-grid/growatt/

CHAPTER 5: RESULTS AND DISCUSSION

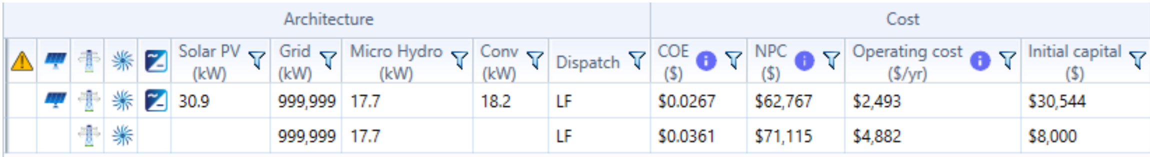
Three alternative combinations of the available resources for the project were simulated to find the most cost-effective combination with the lowest NPC (net present cost) and energy cost.

5.1 CASE 1 Micro Hydro/ Solar/ Grid

In this case, the available resources considered are micro hydro, Solar PV panels, and grid. Homer used the available resources to meet the load demand. After simulation of the project for the mentioned available sources results for the hybrid system were obtained which includes 30.9 KW of Solar panels, and 17.7 KW of hydro. The net present cost of the project comes out to be $62767 and the cost of units produced is $0.0267 with a payback period of 9.20 years. In this case, a major portion of the load was served by Hydro then followed by Solar PV panels. In case of electricity shortage, the load is to be fed by the grid. The excess energy produced by this hybrid system is only 2.34% which can be sold back to the grid.



tabure 5.1: Schematics of CASE 1.



Solar PV (kW)	Grid (kW)	Micro Hydro (kW)	Conv (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)
30.9	999,999	17.7	18.2	LF	$0.0267	$62,767	$2,493	$30,544
	999,999	17.7		LF	$0.0361	$71,115	$4,882	$8,000

Figure 5.2: Architecture of CASE 1.

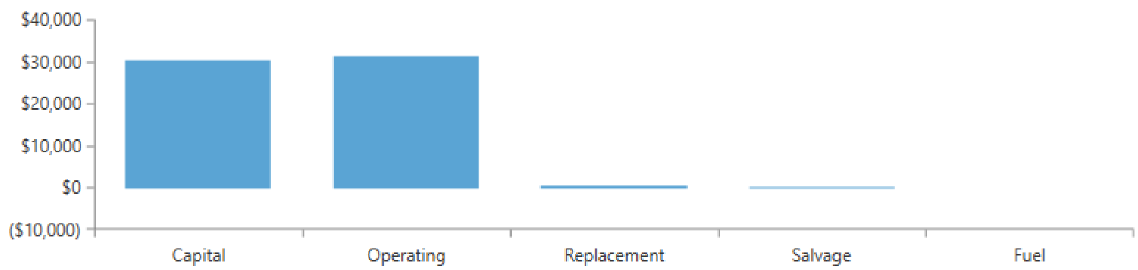


Figure 5.3: Cost analysis of CASE 1.

The schematic diagram for this case is shown in figure 5.4.

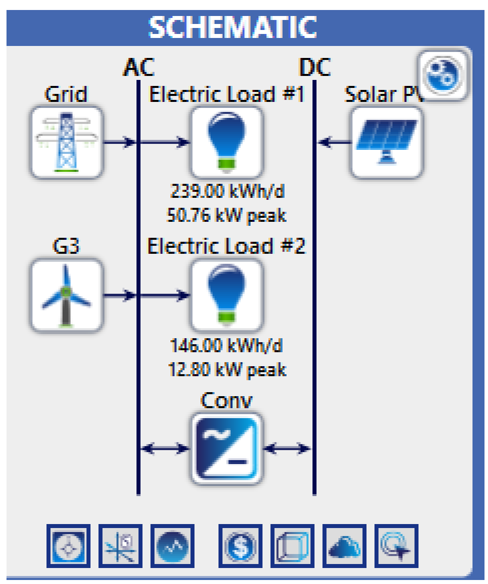


Figure 5.4: Schematic diagram of CASE 1.

Table 5.1: System Architecture of CASE-1

Component	Name	Size	Unit
Micro Hydro	Generic	17.7	kW

PV	Generic flat plate PV	30.9	kW
System converter	Generic system converter	18.2	kW
Dispatch strategy	HOMER Load Following		

Table 5.2: Net Present Costs of CASE-1

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
Micro Hydro	$80000	$0.00	$1292.75	$0.00	$0.00	$9292.75
Canadian Solar Panel	$20362.78	$0	$0	$0	$0	$20362.78
Generic system converter	$2181.49	$925.55	$11750.50	$0.00	$174.20	$14683.34
Grid	$0	$0	$18428.22	$0	$0	$18428.22
System	$30544.27	$925.55	$31471.47	$0	$174.20	$62767.09

Table 5.3: Annual Electricity Production in CASE-1

Electricity Production			**Electricity consumption**			**Quantity**		
Source	kWh/year	Percent %	Load type	kWh/year	Percent %	Quantity	kWh/year	Percent %

Solar	55,439	29.3	Ac	140,525	77.2	Excess electricit y	4421	2.34
Micro hydro	98,611	52.1						
Grid	35,064	18.5	Grid sale	41,618	28.2			
Total	189,115	100	Tota l	182,143	100	Total	4421	2.34

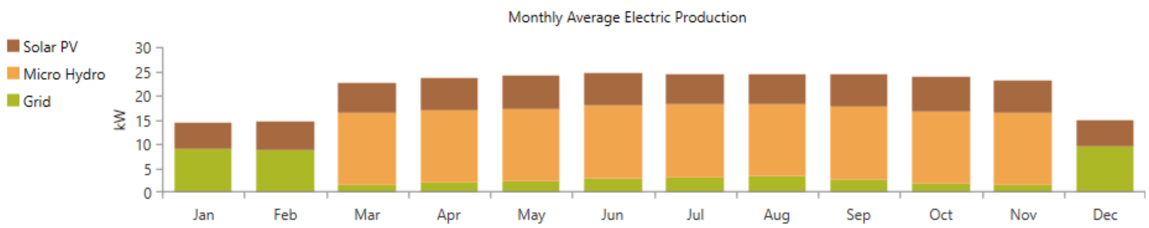


Figure 5.5: Monthly Average Electricity Production of CASE-1

5.2 CASE 2 Solar/Wind/ Grid

In the second case Solar PV, wind, and grid are being taken into consideration. To meet the load Homer will consider these sources and will select the one which has the least net present cost and cost of energy. This combination results in 42.0KW of Solar PV panels and 50kW of wind power plant. The total energy contributed by the PV system is 75415kWh which is 22.7% of the total energy needed. Similarly, the energy produced by the wind power plant is 208998kWh which corresponds to 62.8& of the total energy requirement of the load. Again, this hybrid system is grid-connected which will supply electricity in the absence of renewable energy sources, in this case, the energy that is being drawn from the grid is 4844kWh which is just 14.6% of the total energy requirement. Furthermore, this combination results in a cheap electricity rate as compared to case 1. In this case, the net present cost of the project is $105413, and the cost of energy is $0.0252 with a payback period of 6.20 years.

Architecture					Cost				
Solar PV (kW)	G3	Grid (kW)	Conv (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Re
42.0	50	999,999	24.4	LF	$0.0252	$105,413	$2,342	$75,132	85.
	50	999,999		LF	$0.0318	$114,987	$5,452	$44,500	74.
64.9		999,999	37.3	LF	$0.0642	$151,515	$8,062	$47,289	55.
		999,999		LF	$0.100	$181,664	$14,053	$0.00	0

Figure 5.6: Architecture of CASE-2.

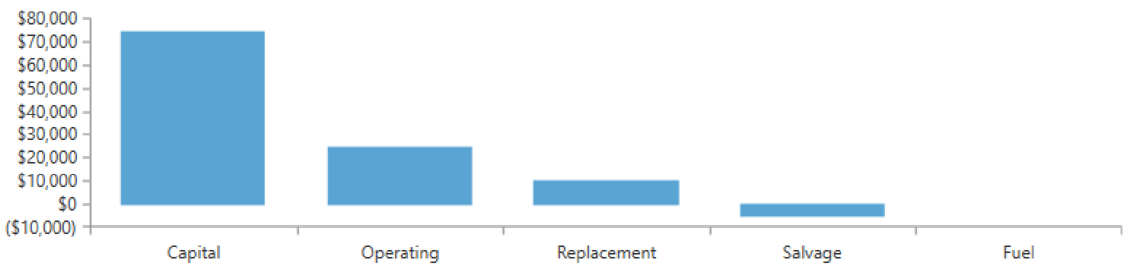


Figure 5.7: Cost Analysis of CASE-2

Table 5.4: System Architecture for CASE-2

Component	Name	Size	Unit
Wind	Generic Biogas Genset (size-your-own)	50	kW
PV	Generic flat plate PV	42	kW
System converter	Generic system converter	24.4	kW
Dispatch strategy	HOMER Load Following		

Table 5.5: Net Present Costs for CASE-2

Component	**Capital**	**Replacement**	**O&M**	**Fuel**	**Salvage**	**Total**
Solar	$27699.76	$0.00	$0	$0.00	$0.00	$27699.76
Wind	$44500	$9564.22	$64637.58	$0	$5390.05	$113311.75
Generic system converter	$2932.04	$1243.99	$15793.34	$0.00	$234.13	$19735.24
Grid	$0	$0	$55333.57	$0	$0	$55333.57
System	$30544.27	$925.55	$31471.47	$0	$174.20	$62767.09

Table 5.6: Annual Electricity Production in CASE-2

Electricity Production			**Electricity consumption**			**Quantity**		
Source	kWh/year	Percent %	Load type	kWh/year	Percent %	Quantity	kWh/year	Percent %
Solar	75,415	22.7	Ac	140,525	43.5	Excess electricity	6,387	1.92
Wind	208,998	62.8						
Grid	48,444	14.6	Grid sale	182,493	56.5			
Total	332,857	100	Total	323,018	100	Total	4421	2.34

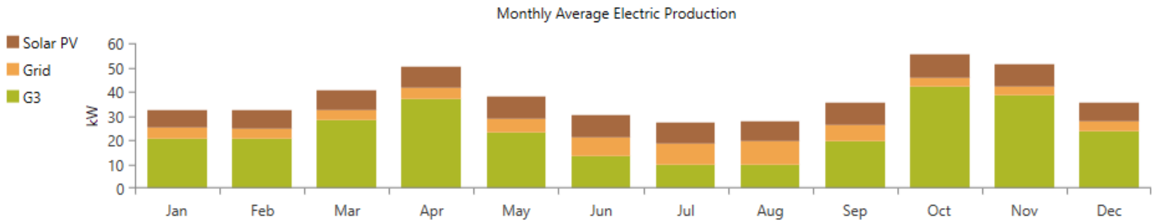


Figure 5.8: Monthly Average Electricity Production.

5.3 CASE 3 Solar/Micro Hydro/Wind/ Grid

In the third case Solar PV, wind, micro-hydro, and grid are being taken into consideration. In this case, all the renewable energy sources have been considered to meet the load. The resources and load specifications have been provided to Homer and the project was simulated which resulted in 16.1Kw of solar PV panels, 50kW of wind power, and 17.7kW of hydro power plant. In this case, the net present cost of the project is $28514 which is quite a lesser amount as compared to that in case 1 and case 2, and the cost of energy is $0.006274 with a payback period of 7.02 years. The reason for its economical cheapness is that in this case 27.8% of energy was supplied by micro which is cheaper than both wind and Solar PV. A schematic diagram for case 3 is shown in Figure 5.9 and annual energy production is depicted in Table 5.9 and is visualized in Figure 5.12.

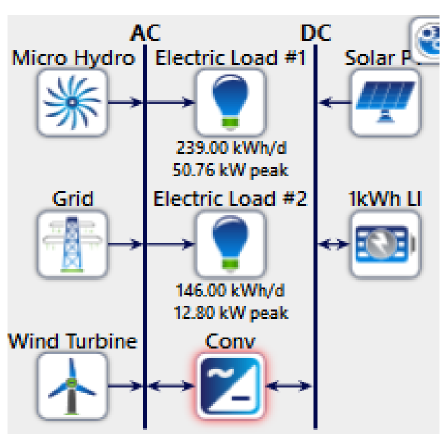


Figure 5.9 : Schematics of CASE-3

Architecture					Cost				
Solar PV (kW)	Grid (kW)	Micro Hydro (kW)	Conv (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Re
30.9	999,999	17.7	18.2	LF	$0.0267	$62,767	$2,493	$30,544	80
	999,999	17.7		LF	$0.0361	$71,115	$4,882	$8,000	64

Figure 5.10: Schematic Diagram for CASE-3.

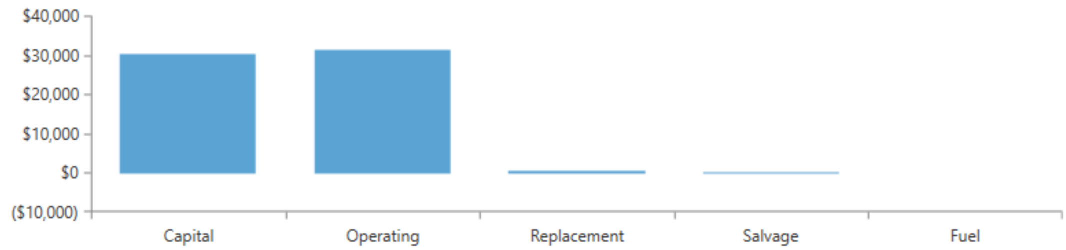


Figure 5.11: System Architecture cost comparison of CASE-3.

Table 5.7: System Architecture of CASE-3

Component	Name	Size	Unit
Wind	Generic Biogas Genset (size-your-own)	50	kW
PV	Generic flat plate PV	16.1	kW
Micro hydro	Generic	17.7	Kw
System converter	Generic system converter	9.68	kW
Dispatch strategy	HOMER Load Following		

Table 5.8: Net Present Costs of CASE-3

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
Solar	$10596.69	$0.00	$0	$0.00	$0.00	$10596.69
Wind	$44500	$9564.22	$64637.58	$0	$5390.05	$113311.75
Micro Hydro Generic	$8000	$0	$1292.75	$0	$0	$9292.75
Generic system converter	$1162.03	$493.02	$6259.25	$0.00	$92.79	$7821.51
Grid	$0	$0	$112508.57	$0	$0	$112508.57
System	$64258.73	$10057.24	$40318.98	$0	$5482.84	$28514.14

Table 5.9: Annual Electricity Production in CASE-3

Electricity Production			**Electricity consumption**			**Quantity**		
Source	kWh/year	Percent %	Load type	kWh/year	Percent %	Quantity	kWh/year	Percent %
Solar	28850	8.13	Ac	140525	43.5	Excess electricity	2031	0.572

Wind power	208998	58.9	Dc	0		Unmet load	0	0
Micro hydro	98611	27.8						
Grid	18502	5.21	Grid sale	211064	60			
Total	332857	100	Tota l	351589	100	Total	2031	0.572

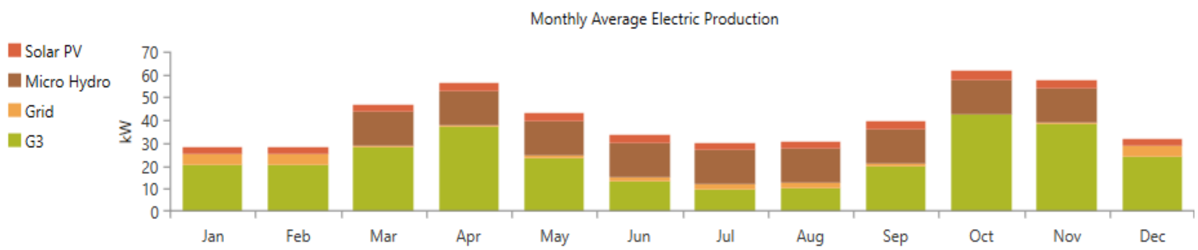


Figure 5.12: Monthly Average Electricity Generation in case 3

5.4 Cost Comparison of Three Cases

Cost comparison of all the three cases is summarized in table 5.10. The results dictate that the cheaper case is case number 3 with NPC $28514 and COE as $0.006274. This least cost of energy can be justified by the cheapest power source that is micro hydro power plant.

Table 5.10: Cost comparison of the above three cases

	Cost of energy-in $	NPC in $	Operating Cost in $/year	Payback Period in years
Case 1	0.0267	62767	31471	9.20
Case 2	0.0252	105413	25097	6.02
Case 3	0.006274	28514	40318	7.02

5.5 System Level Diagram

Figure 5.13 shows the system Level diagram including energy sources such as Wind, Solar, Micro hydro and grid and load such as Water pump load and Domestic load.

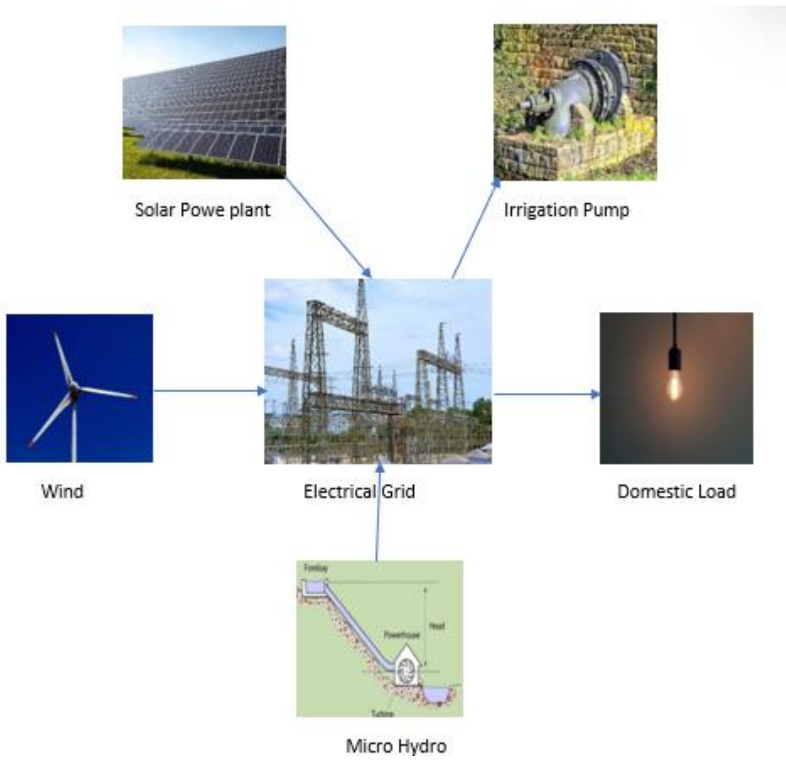


Figure 5.13: System Level Diagram

CHAPTER 6: CONCLUSION AND FUTURE WORK

In conclusion of this research pursuit, a hybrid energy system rises as the primary focus that combines Solar PV Wind power plant Micro-hydro and Grid technologies. The main purpose of this study is to develop an affordable and sustainable energy solution that would be able to supply electricity for the whole range of needs in a small village with 30 houses including one water pump which is very critical when we speak about irrigation. Various options with available resources were also carefully simulated using HOMER to understand which configuration could be the most economical and efficient.

In the quest for improving efficiency in utilizing resources, three unique configurations were meticulously assessed before arriving at a strategic fusion of solar PV placed together with wind power plant and micro hydropower facility attached to grid integration. This synergy had an NPC of $28,514 with COE being at the rate of 0.006274 and having an impeccable payback period within which it could be recovered was measured in years thus reading 7. The results of this model are rather compelling, and they fully confirm the economic feasibility and viability of the proposed hybrid energy solution as something that could become a very reliable source of electricity for all components identified above.

Considering the future, several avenues emerge for further investigation and improvement of the proposed hybrid energy system. In the first place, sustainable energy technologies are constantly generating new advancements that deserve constant study to integrate current innovations in order to boost system efficiency or lower overall cost. Secondly, considering the variable nature of environmental factors, a deeper study about adaptive control approaches for hybrid systems could also be helpful. This could also include implementing smart grid type technologies or more advanced energy storage solutions to improve the resilience of our system under varying levels of resources available.

In addition, community engagement and empowerment projects should be investigated so that the hybrid energy system can easily find its place in the daily life of residents. The long-term success and sustainability of the project can be significantly influenced by four aspects involving stakeholder involvement, awareness programs as well as capacity building efforts. Further, with the constant development of technology, regular updates and maintenance strategies should be considered for keeping hybrid energy systems up-to date in terms of efficiency and reliability.

In summary, the hybrid energy system being developed during this paper not only represents a present model to address the issue of providing the village with electricity but also opens doors for further development and advancements. As a result of continuous research, community-related activities, and technological innovations the above proposed system can be utilized as an illustration for socially responsible energy solutions that promote shifts in paradigms towards cleaner and more cost-effective electricity generation possibilities designed to benefit rural communities.

6.1 Future Work

The conclusion of this research opens the door to several promising avenues for future work and advancements in the realm of hybrid energy systems:

- Continuous development of solar PV, wind power and micro-hydro technologies can enable the incorporation of even more effective yet affordable elements. Evolving the technologies associated with energy storage solutions like enhancing batteries or introducing new capacitors can also improve hybrid system reliability and stability.

- Future studies may focus on the implementation of smart grid technologies. Intelligent grid systems would help to distribute electricity in the most optimized way, could manage peak loads more efficiently and hence raise the efficiency of hybrid energy system. This might include sophisticated control algorithms, real time monitoring and demand response mechanisms.
- Research can also focus on investigating more modern, high-capacity batteries or new technologies that might come up for instance flow energy storage devices and super capacitors. For ensuring a steady power supply, even when the generation of renewable energy is low, effective storage of energy plays an integral role in system reliability.
- The sustainable deployment of the hybrid energy system will require conducting thorough environmental impact assessments. Further studies could focus on determining the environmental benefits, carbon footprint decrease and life cycle assessments to have a better perspective of how that system affects our ecosystem.
- Other studies should focus on community engagement strategies highlighting the social and financial effects that a hybrid energy system can have on locals. This can be through such participatory research methods, awareness drives or use of educational programs to make sure that the community members are actively involved and supportive.

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